LIU beam performance ramp-up

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HiLumi WP2 – 25.07.2023

Outline

- LIU performance ramp-up plan
- PSB and PS achieved performance
- SPS achieved performance
- Summary & Outlook

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- **LIU performance ramp-up plan**
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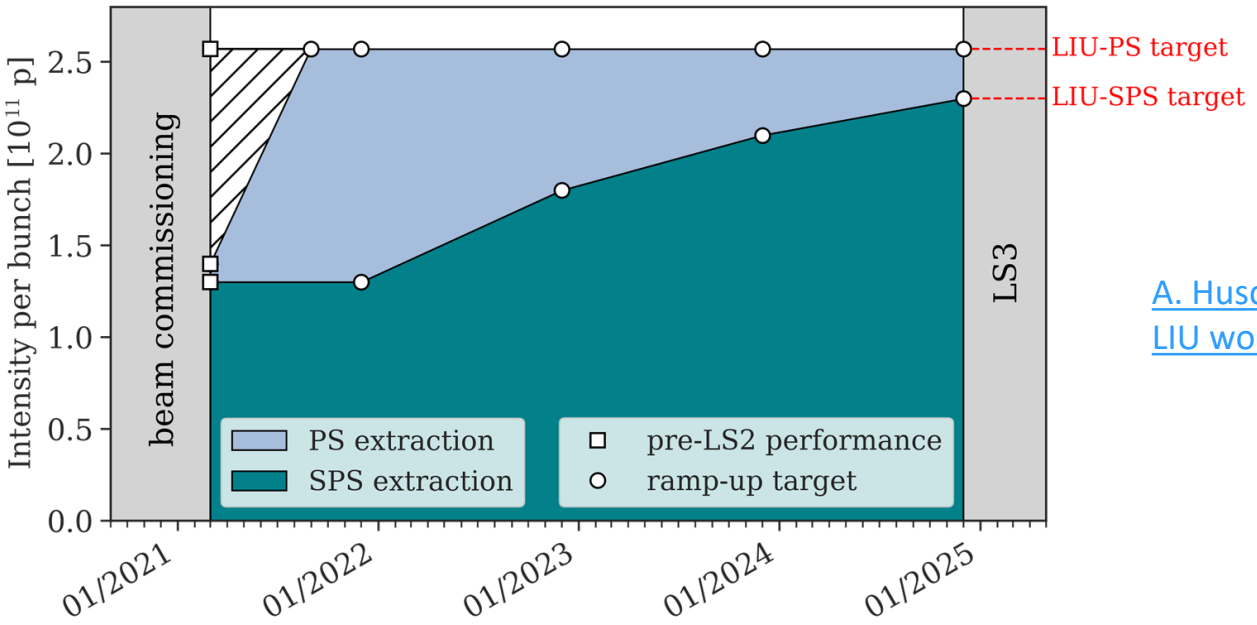
LIU performance ramp-up plan



A. Huschauer et al., LIU workshop 2020

- **Intensity goals of the ramp-up at SPS extraction**
  - 1.8e11 p/b in MD by the end of 2022 – to be ready for LHC in 2023
  - 2.1e11 p/b in MD by the end of 2023 – to be ready for LHC in 2024
  - 2.3e11 p/b in MD by the end of 2024

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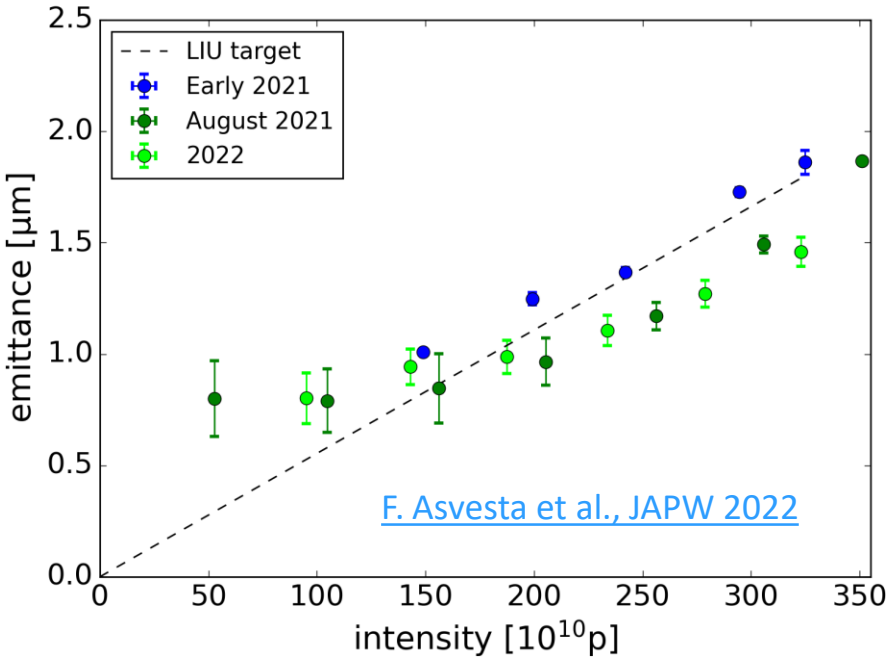
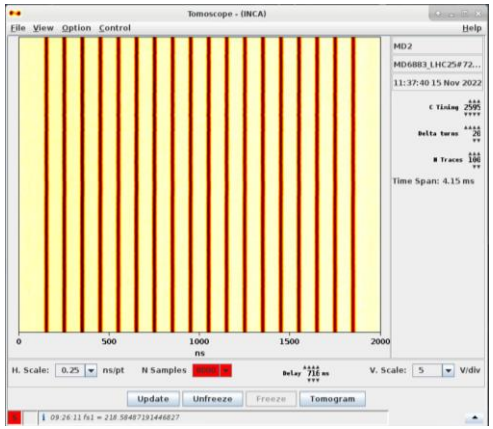
PSB delivering LIU beams

- **Very smooth commissioning of new PSB injection after LS2**
  - Including dynamic beta-beat compensation during collapse of injection chicane
  - Machine performance in very good agreement with simulation models
- **PSB delivering LIU brightness (and beyond!) already since 2021**

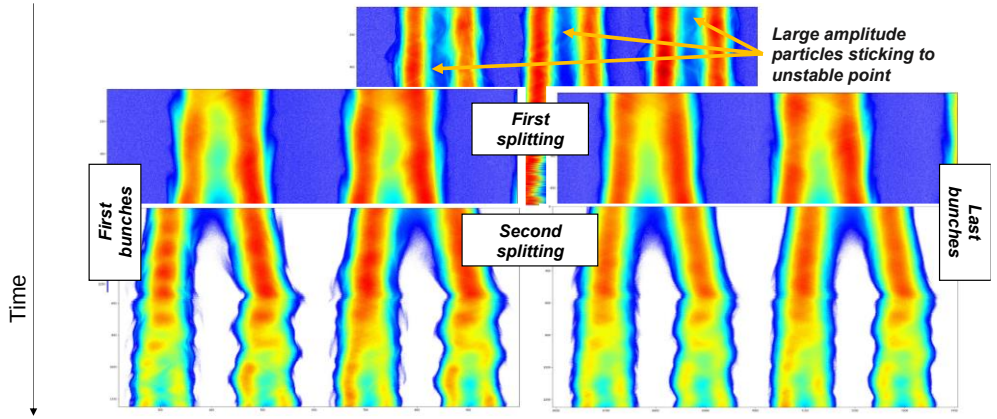


PS demonstrated beyond LIU target intensity

- **LIU bunch intensity of 2.6e11 p/b already recovered in 2021**
- **Achieved intensities stably up to 3e11 p/b – for higher intensities:**
  - Quadrupolar longitudinal coupled-bunch instabilities during acceleration
  - 40 MHz RF system as Landau cavity provides sufficient stability
  - Alternatively can be achieved by newly developed **Quadrupole-mode feedback**
- **Since LIU target intensity is exceeded with a good margin, the focus is now on beam quality and reproducibility**



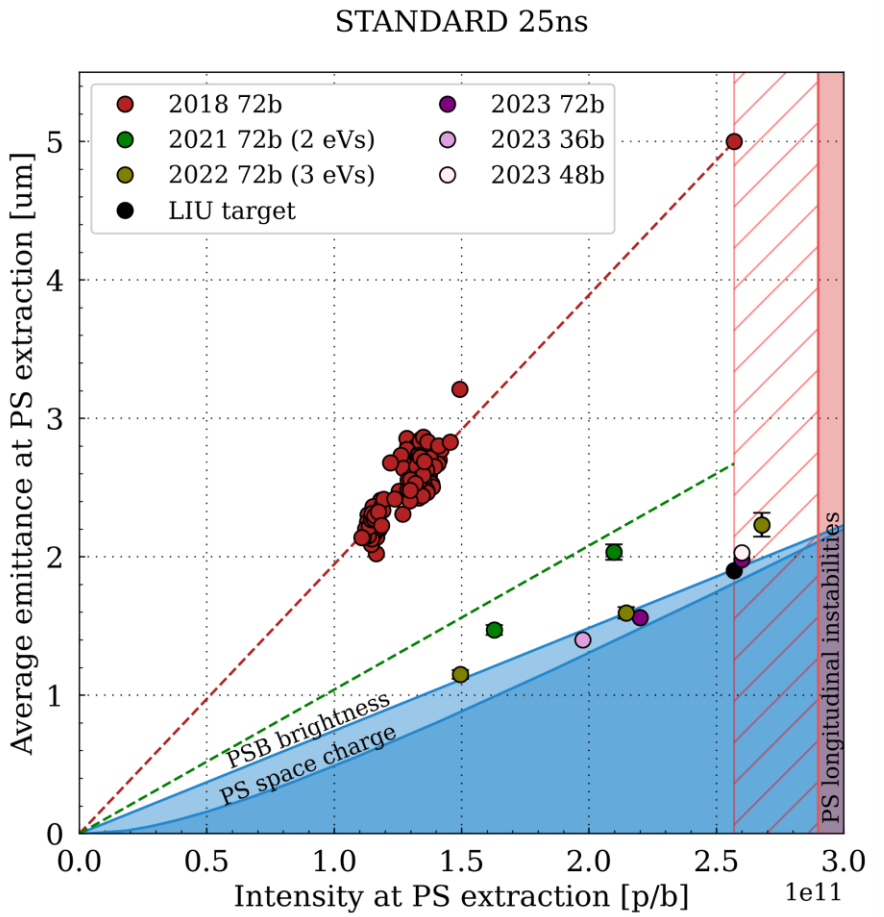
I. Karpov et al., JAPW 2022



At LIU intensity, these oscillations can cause longitudinal halo

PS operating at LIU brightness

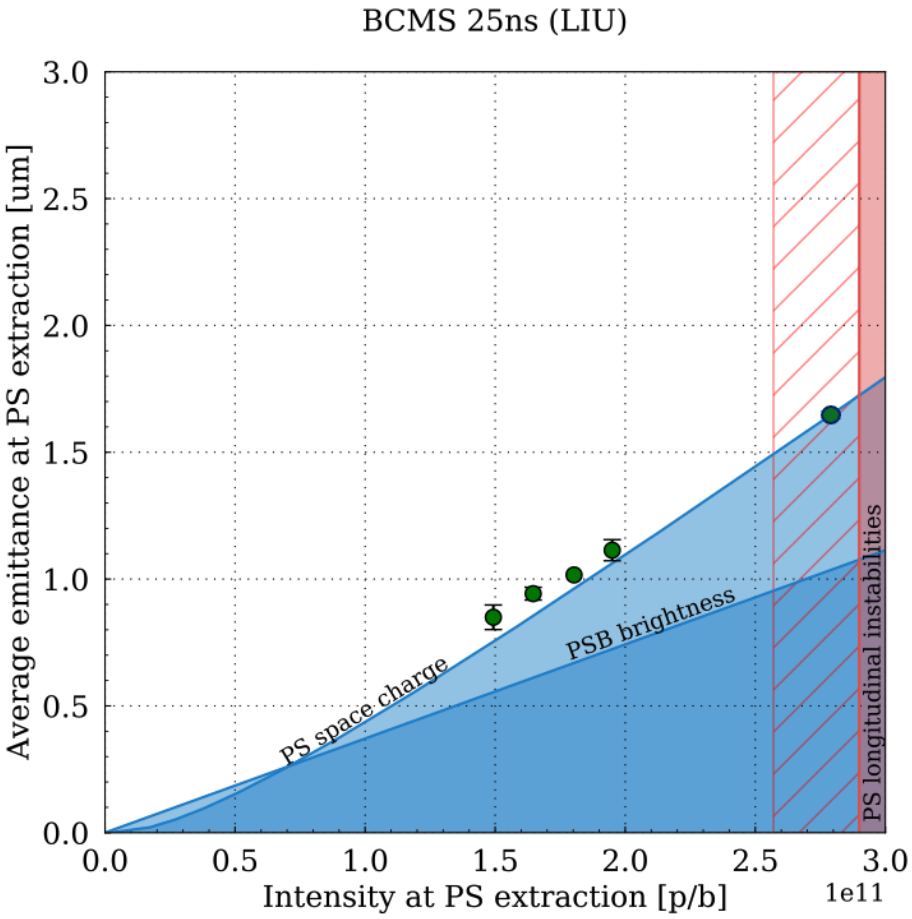
- **Commissioning of 3 eVs longitudinal emittance in PSB in 2022 made the final step in the brightness ramp-up for the PS**



LIU beam parameters at PS extraction reached

BCMS beam in the PS

- **Measurements from 2022 – close to LIU brightness also for BCMS beam**



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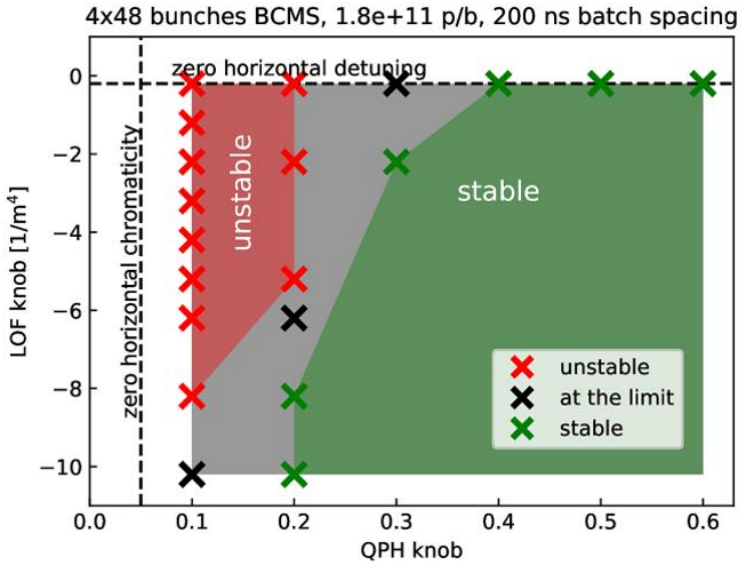
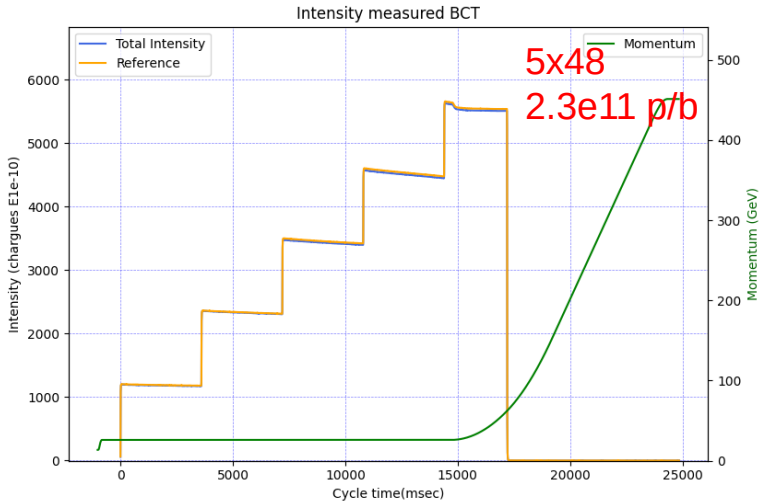
Horizontal instabilities at SPS flat bottom

- **Horizontal instability characterized in detail in 2018 for 1.8e11 p/b**
  - Mitigation strategy developed in simulations: **high chromaticity + octupoles**
- **Successfully tested in 2022 for BCMS beams**
  - **5x48 bunches with 2.3e11 p/b ramped to ~50 GeV**
  - About 95% overall transmission at peak performance

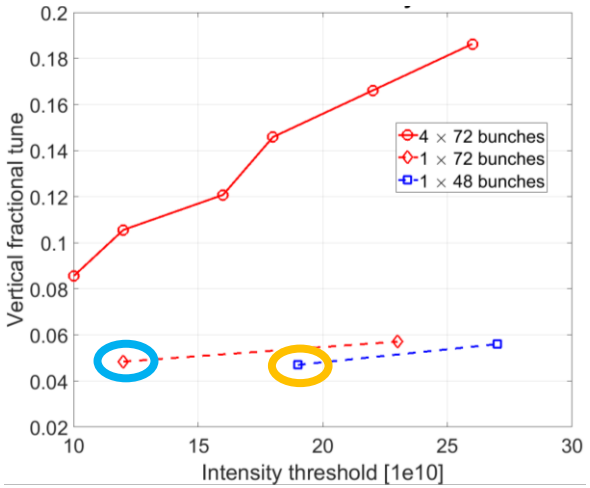


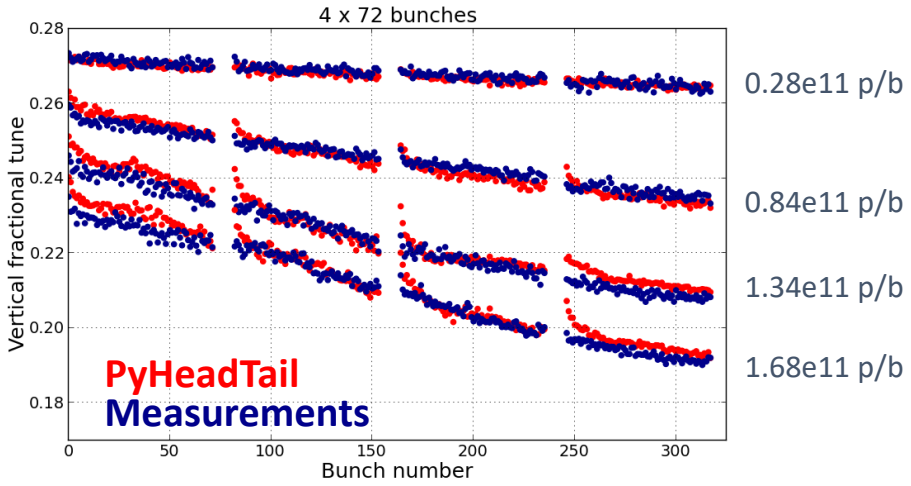
C. Zannini et al., JAPW 2022



Vertical coupled bunch instability on SPS flat bottom

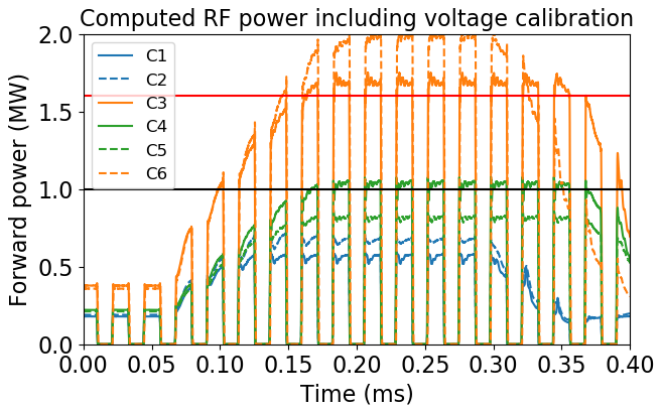
- **Predicted in simulations performed during LS2**
  - Extremely fast instability (only few turns risetime)
  - Threshold depends on vertical tune setting (resistive wall instability)
- **Experimentally confirmed with 1 batch and low intensity**
- **Vertical tunes close to 20.25 resonance required for LIU parameters**
  - **Control of tunes is critical** due to large tune shift from impedance (“Laslett correction”) – excellent progress on simulations an operational correction

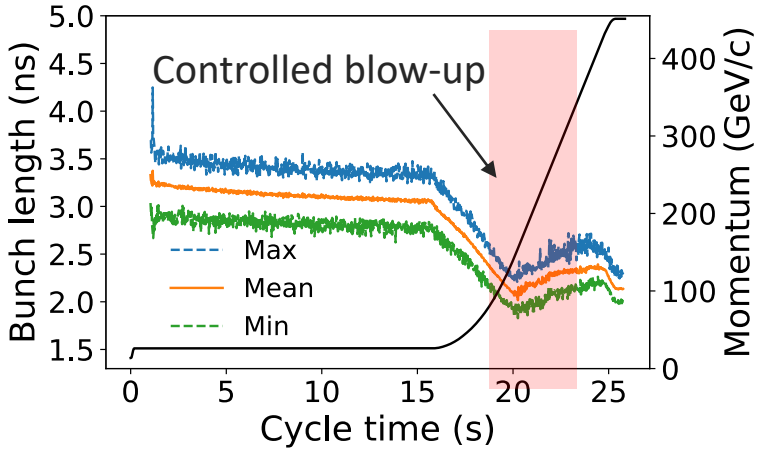




Intensity ramp-up in the SPS – Longitudinal aspects

- **Successful commissioning of new RF system in 2021 and 2022**
  - 1-turn delay feedback, feedforward, longitudinal damper, amplitude modulation
  - **Nominal RF voltage and power available on 4 out of 6 cavities** (SIEMENS plant only 800 kW), failure rate of solid-state amplifier modules to be understood
  - **Significantly improved transmission in the ramp!**
- **Longitudinal stability in check**
  - thanks to optimized voltage program (higher voltage at flat top) and controlled emittance blow-up (with automatized setup)



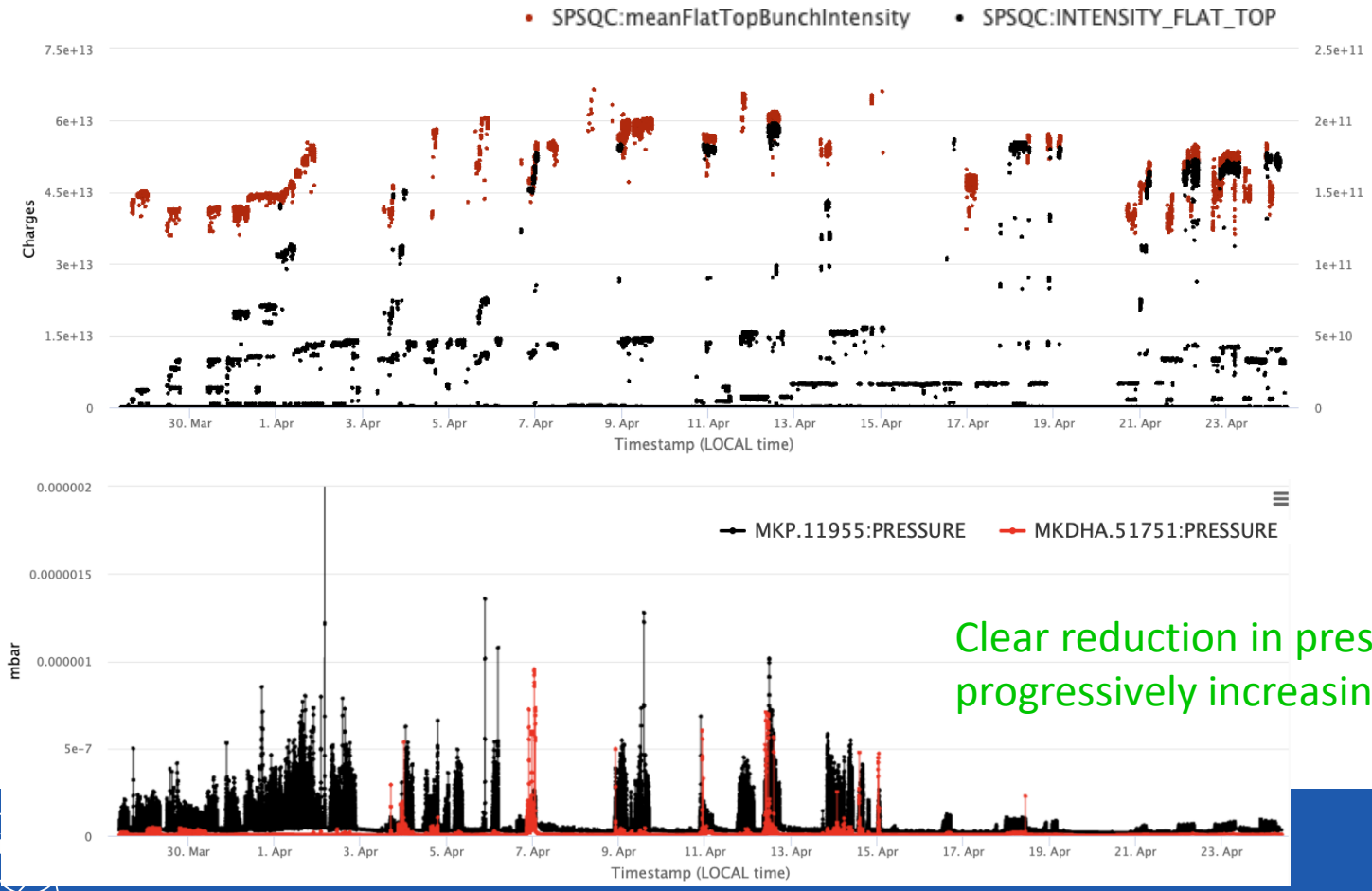


Scrubbing

- **Pressure rise at MKDH limited intensity to 1.8e11 p/b in 2022**
  - MKDH is the original beam dump kicker from SPS construction
  - Unpredictable pressure spikes at flat top with short bunches

Scrubbing

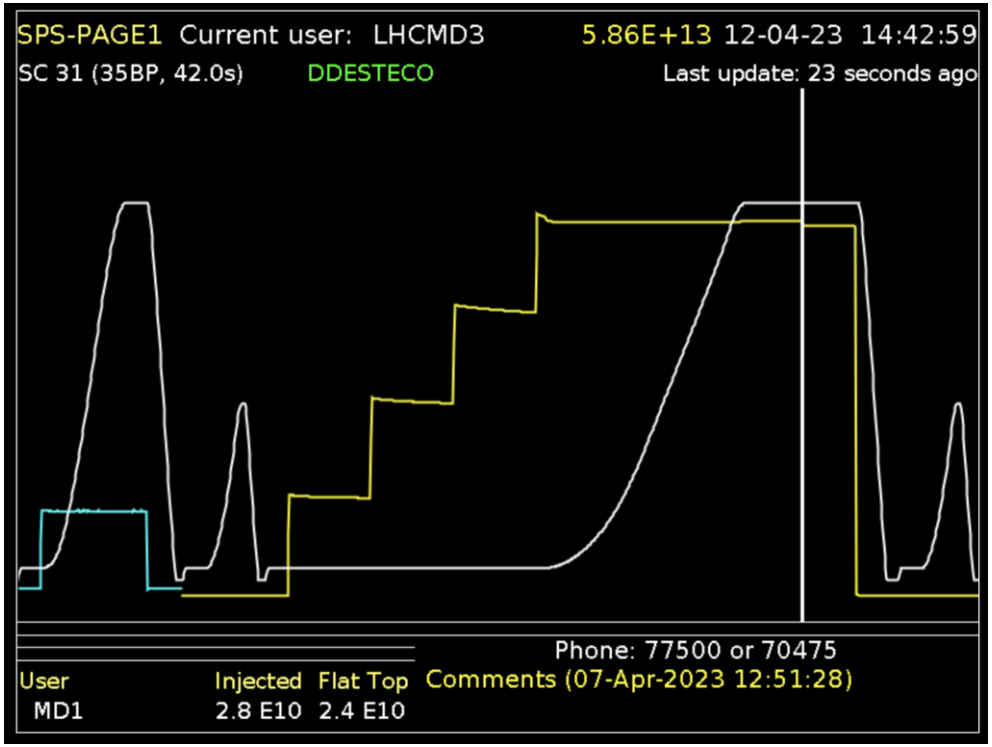
- Pressure rise at MKDH limited intensity to 1.8e11 p/b in 2022
- Scrubbing took 1 month in 2023 to condition MKDH and new MKP-L



Clear reduction in pressure rise with progressively increasing intensity

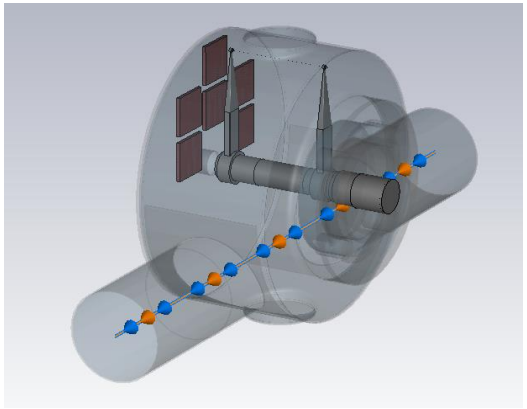
Scrubbing

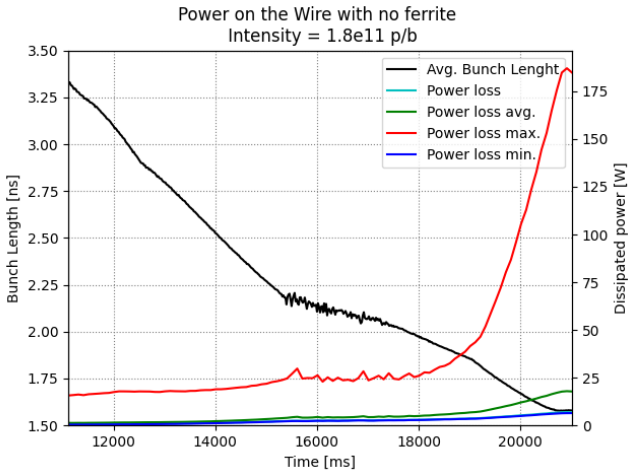
- **Pressure rise at MKDH limited intensity to 1.8e11 p/b in 2022**
- **Scrubbing took 1 month in 2023 to condition MKDH and new MKP-L**
  - Using cycle with long flat top at 400 GeV + improved vacuum interlock logics gave huge improvement in scrubbing efficiency

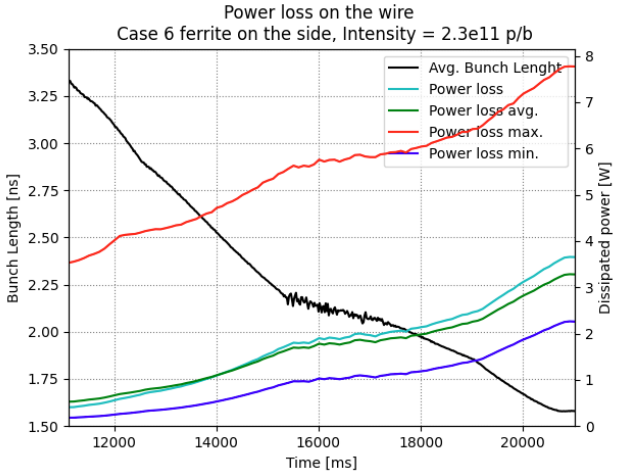


Issue with SPS wire scanners

- **After the scrubbing period realized that wires of all 4 wire scanners broke**
  - New wires were installed in sextant 4, but the broke again after a short while when accelerating the beam (normal flat top length, intensity 1.8e11 p/b)
- **Mitigation strategy developed by SPS wire scanner task force**
  - Suspect impedance at around 800 MHz at origin of failure
  - Installation of ferrites during technical stop to significantly reduce wire heating
  - Observed clear improvement on online “wire temperature” measurement

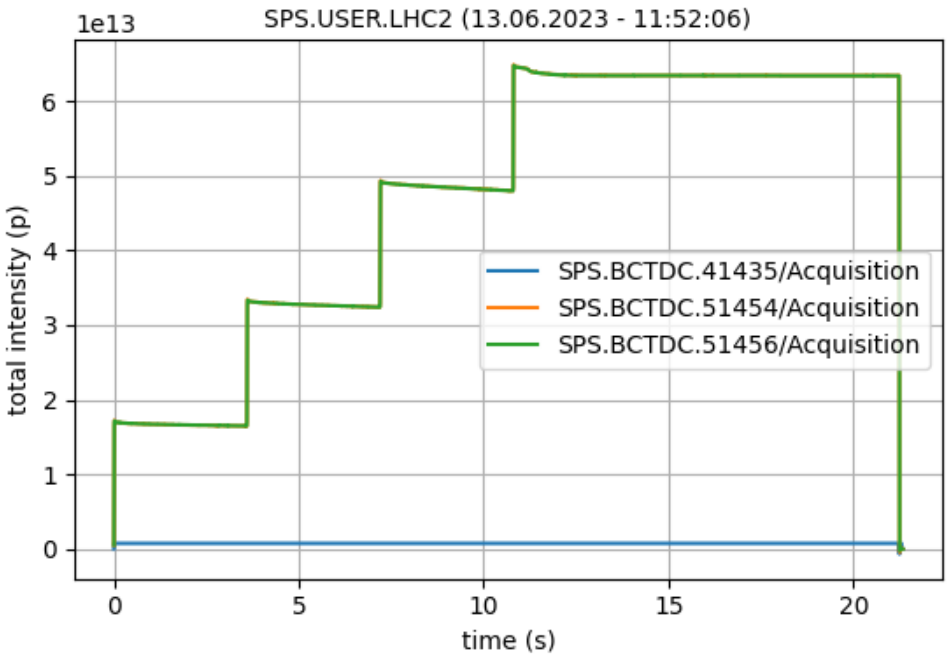


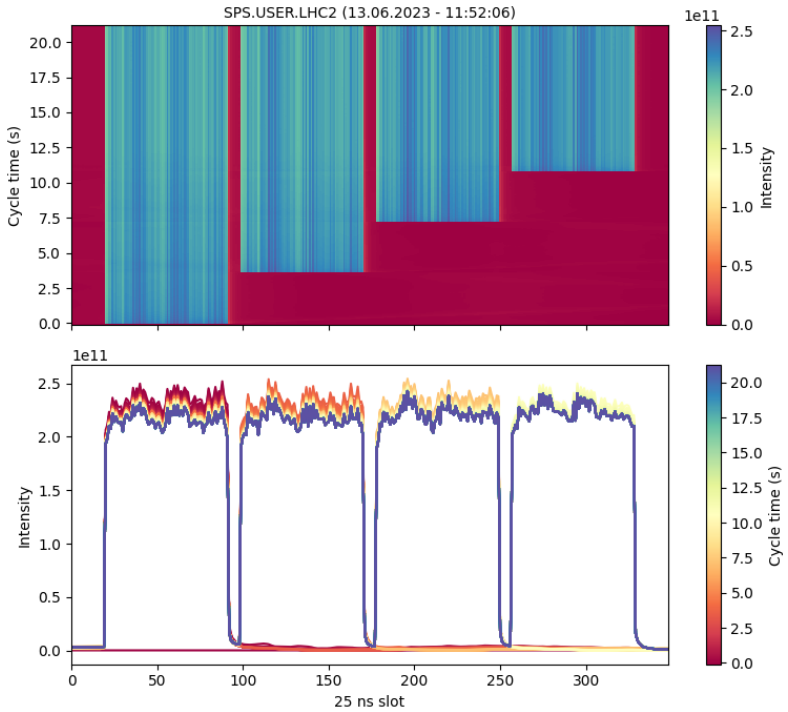




SPS performance achievements – intensity

- **Intensity record from 13.06.2023: 4x72 with 2.2e11 p/b at flat top**
  - Excellent transmission (~95% without scraping)





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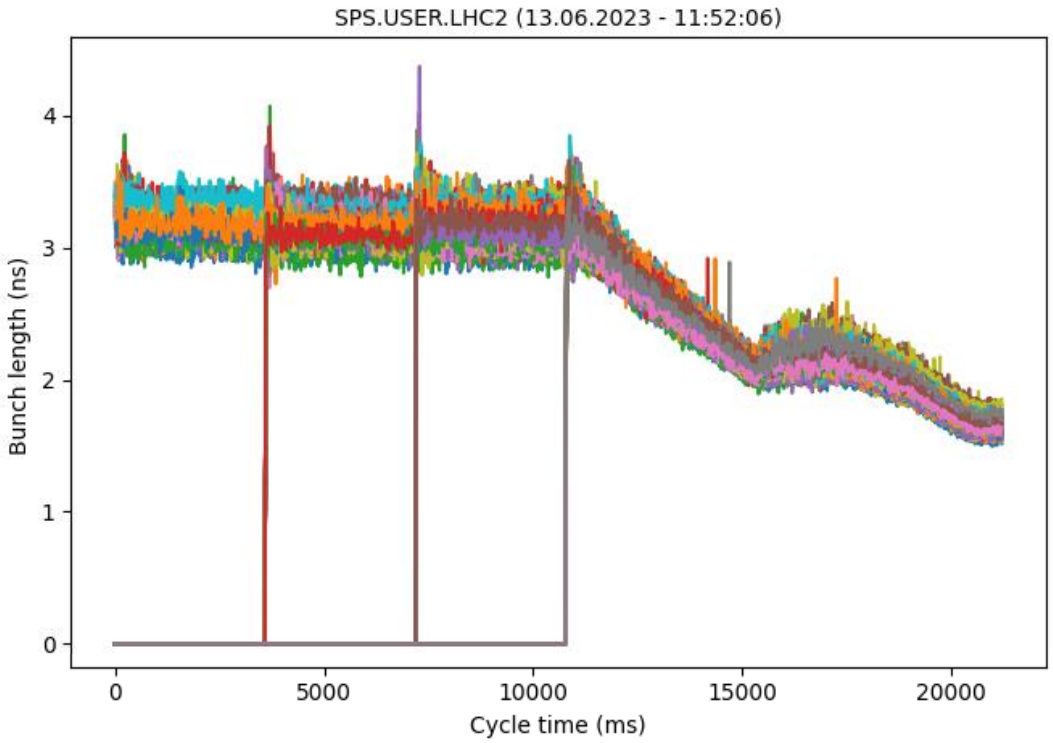

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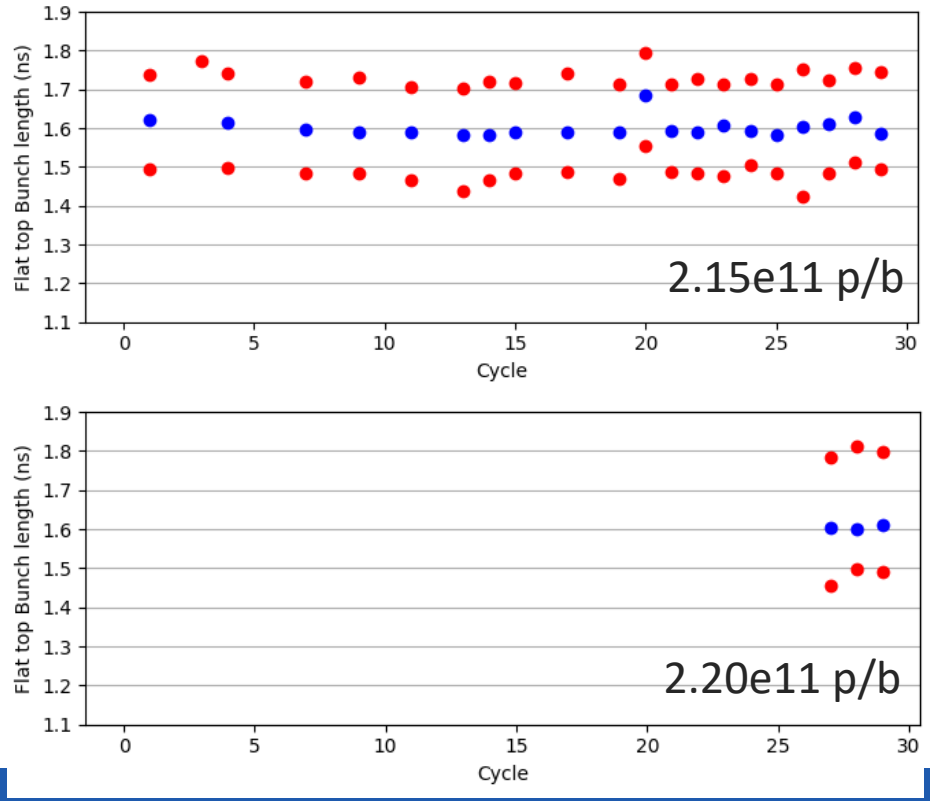
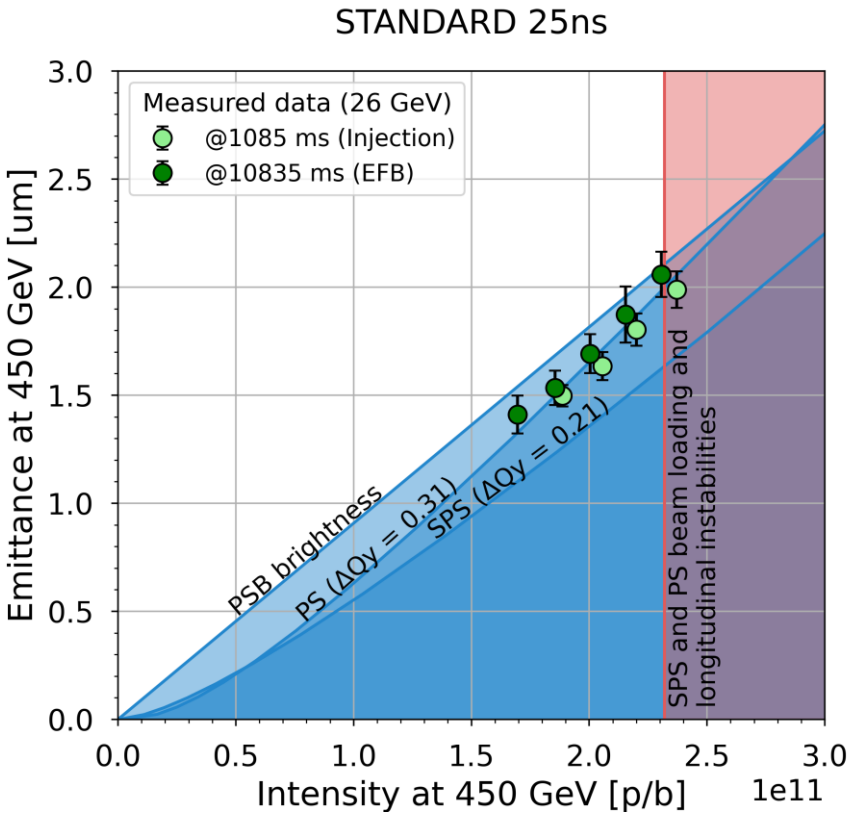
  - Excellent transmission (~95% without scraping)
  - Longitudinally stable (controlled long. emittance blow-up, voltage program)
  - Bunch length at flat top around 1.6 ns – reproducibly!



SPS beam performance achievements – brightness

- **LIU target brightness for standard beam reached (end of SPS flat bottom)**
  - Measurements for BCMS beam planned for upcoming MDs



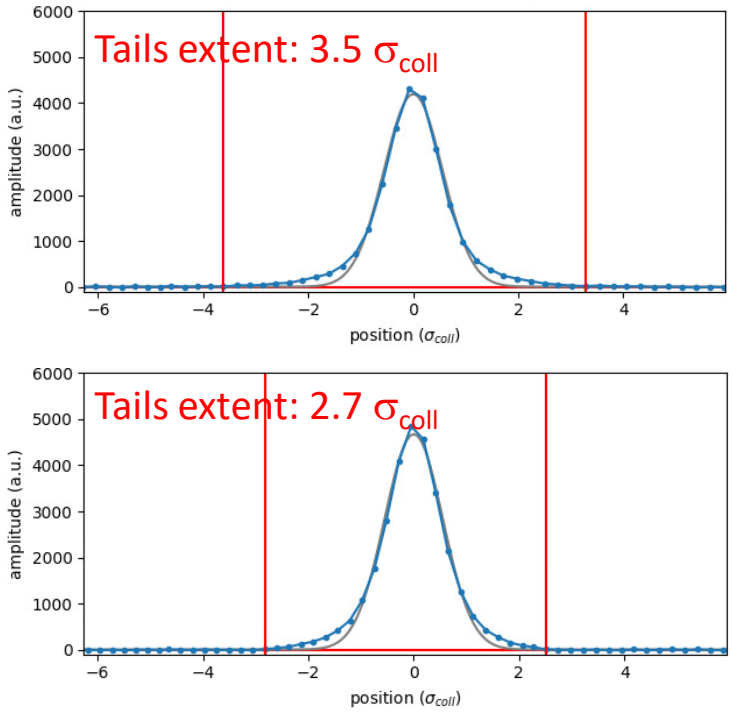
Measurements from July 2023 with 4x72 bunches

Transverse tails

- **Transverse beam profiles show large transverse tails**
  - Lots of studies to characterize the tails (q-Gaussian fits, parallel readout of different photomultipliers of the wire scanners)
  - Found tails in the PSB, additional tail creation at PS transition crossing and in SPS

Horizontal profiles in SPS

SPS scraping



F. Asvesta et al., JAPW 2022

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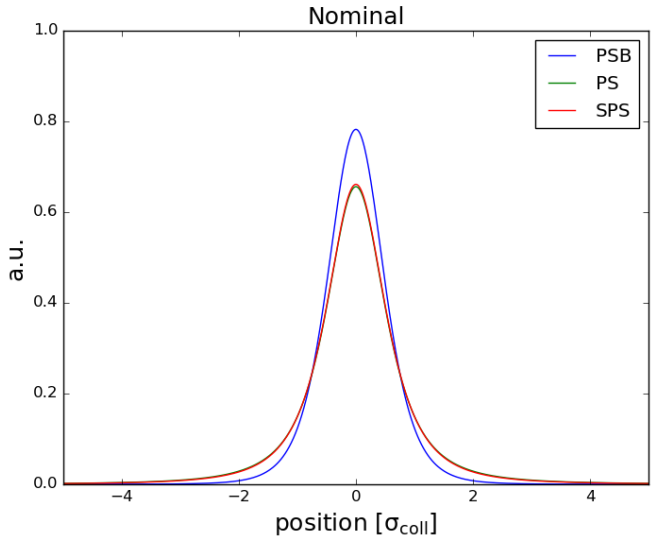
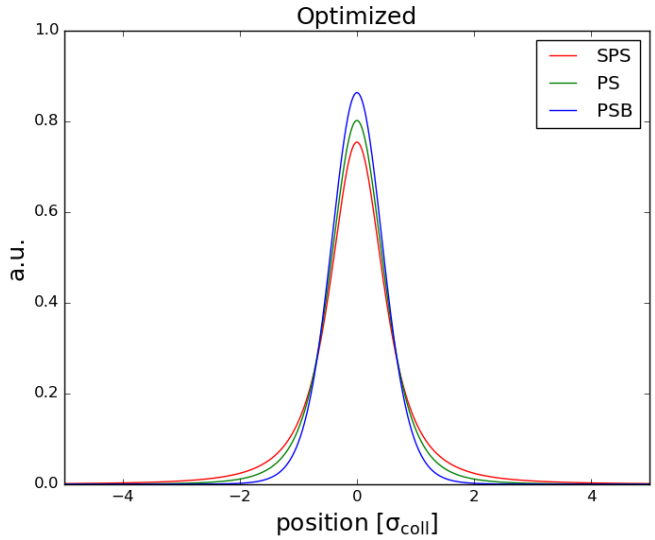
  - Found tails in the PSB, additional tail creation at PS transition crossing and in SPS
- **Optimizations applied in the PSB and the PS (especially in vertical)**
  - Improvement not clear yet in the SPS (and LHC)





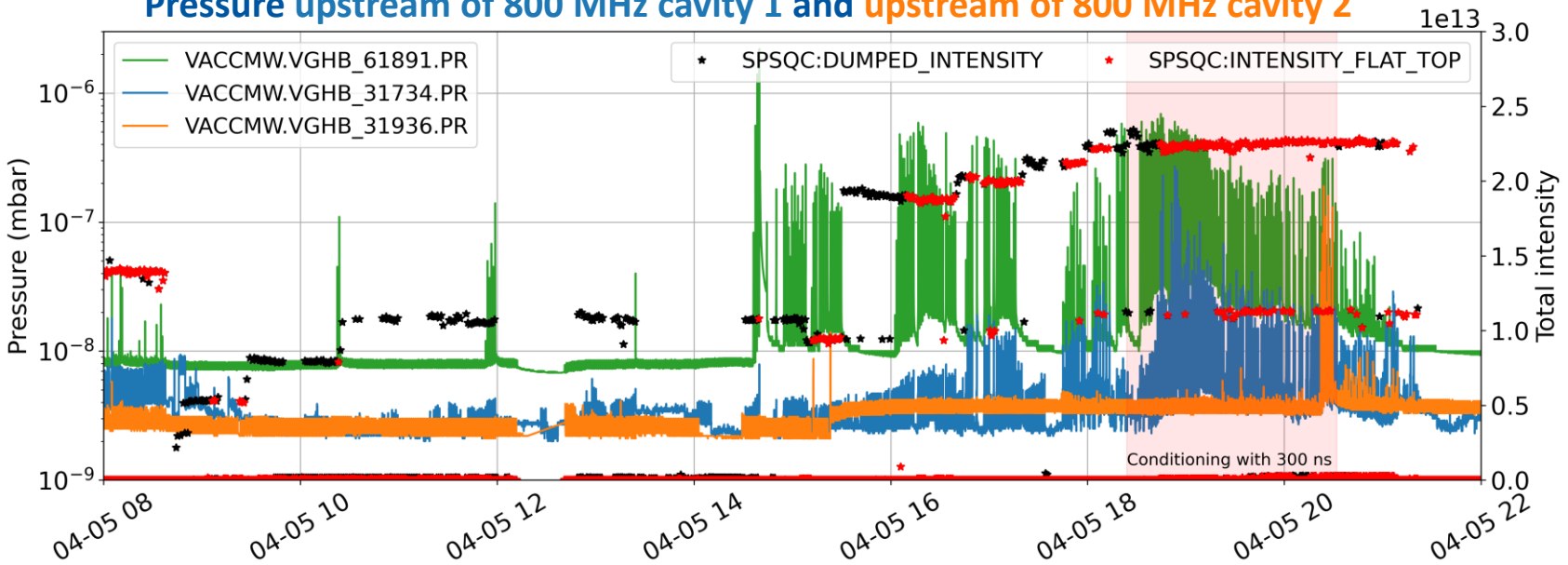
F. Asvesta et al., JAPW 2022

8b4e beam

- **Pressure spikes at 800 MHz cavity 1 limited intensity of 8b4e beam in 2022 to 1.8e11 p/b with 2 batches of 56 bunches**
- **First tests in 2023 very promising**
  - Clear conditioning observed with 2x56 bunches – could reach 2.2e11 p/b
  - To be continued with more batches and higher intensity

I. Karpov et al. at IPP, 21.04.2023

Pressure upstream of 800 MHz cavity 1 and upstream of 800 MHz cavity 2



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Summary and outlook

- **Achieved intensities**

year	Intensity at FT [p/b]	# of bunches	Batch spacing [ns]	Bunch length [ns]	Beam type	Date
2023	2.2e11	4 x 72	200	1.6	Standard	13.06.
2023	2.0e11	2 x 56	250	1.6	8b4e	05.04.
2023	1.8e11	56 + 5 x 36	200	1.6	hybrid	19.05.

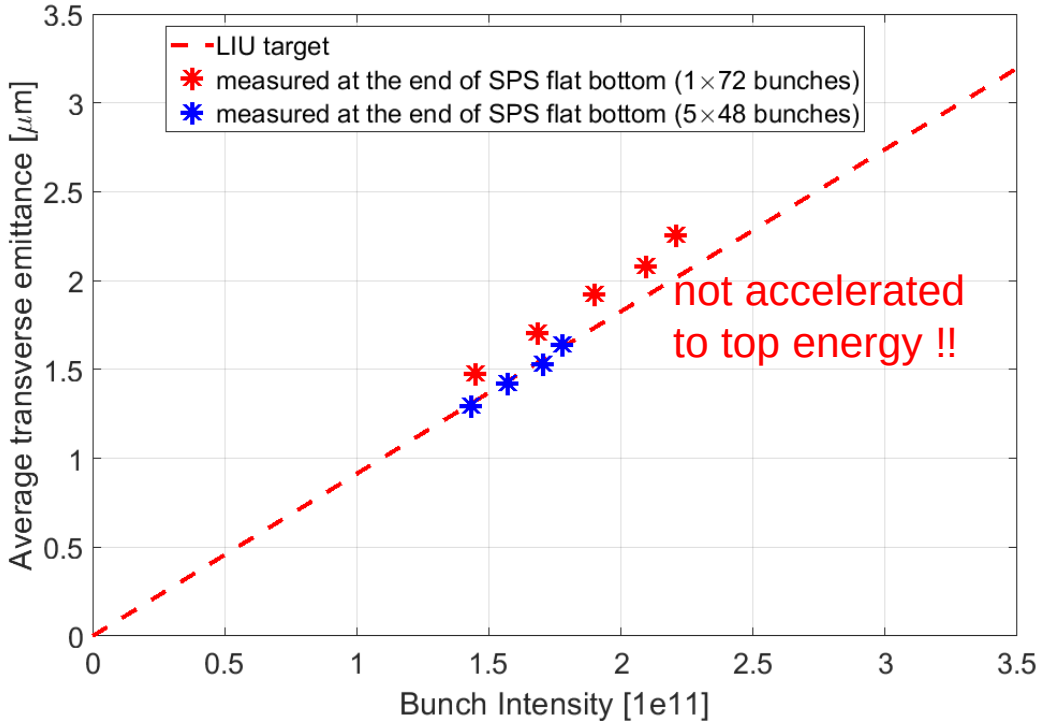
- **Next steps**
  - Demonstrate LIU target intensity (2.3e11 p/b) at flat top
  - Half-day event on strategy for kicker conditioning and possible future upgrades
  - Minimize tails in transverse beam profiles
  - Losses at PS-2-SPS transfer and flat bottom losses
  - Need for high bandwidth feedback system to ensure transverse stability?
  - Need for coating of SPS or is scrubbing sufficient?
  - Study 8b4e intensity reach beyond 2.3e11 p/b as requested by HL-LHC

Thanks for your attention

BACKUP

SPS achieved brightness at end flat bottom

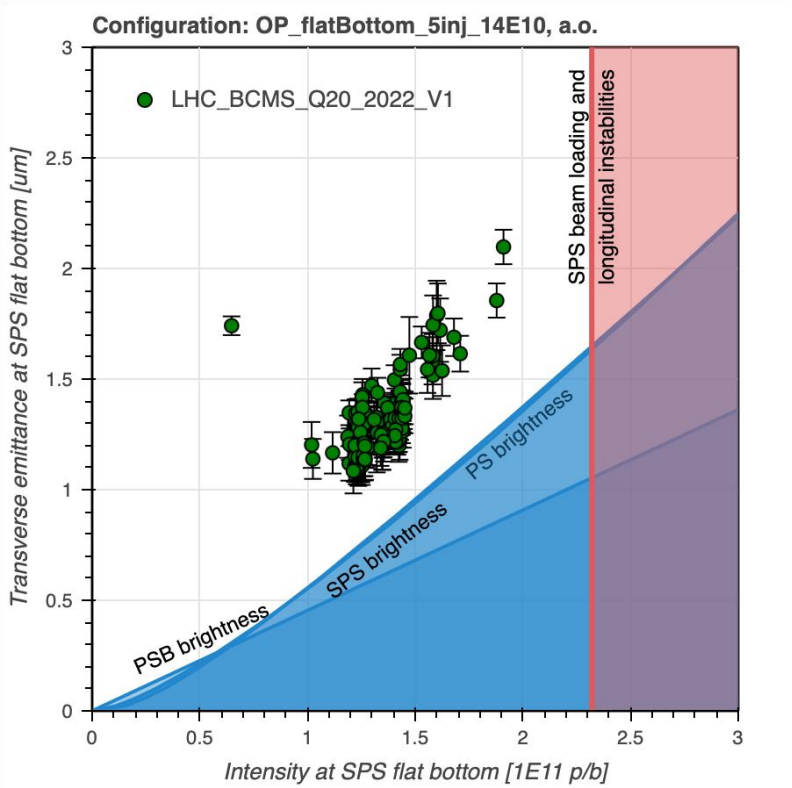
- **Good brightness also in the SPS with some room for improvement**
  - Measurements at end flat bottom (wire breakage for full trains at flat top)
  - **Further working point optimization to be performed in 2023** (considering beam stability and impact on transmission)



C. Zannini et al., JAPW 2022

Achieved beam parameters

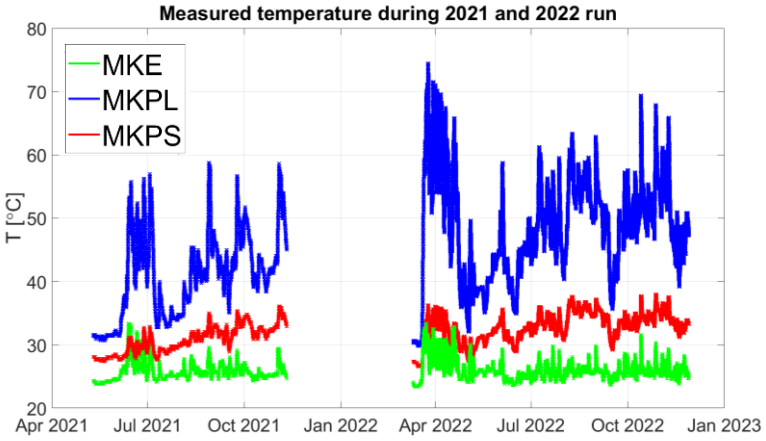
- **Operationally delivered BCMS beams (5x36 bunches) up to 1.5e11 p/b**
  - Large scraping had to be used to avoid losses at LHC injection (see later)



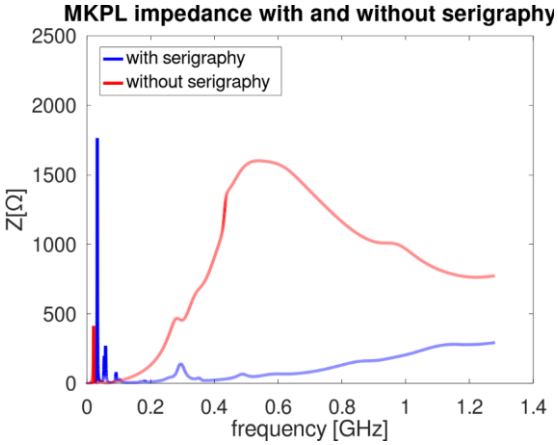
Beam induced heating of SPS injection kicker MKP-L

- **Heating and outgassing limit continuous operation with LHC beams**
  - In 2022 SY-ABT increased temperature limit to cope with scrubbing and high intensity MDs (MKP-L heating much worse than MKP-S)
- **Low impedance upgrade of MKP-L – installation presently ongoing**
  - Serigraphy for impedance reduction (final configuration with very good HV behaviour) + coating to minimize e-cloud
  - **Estimated to need about one week of scrubbing at the beginning of 2023**

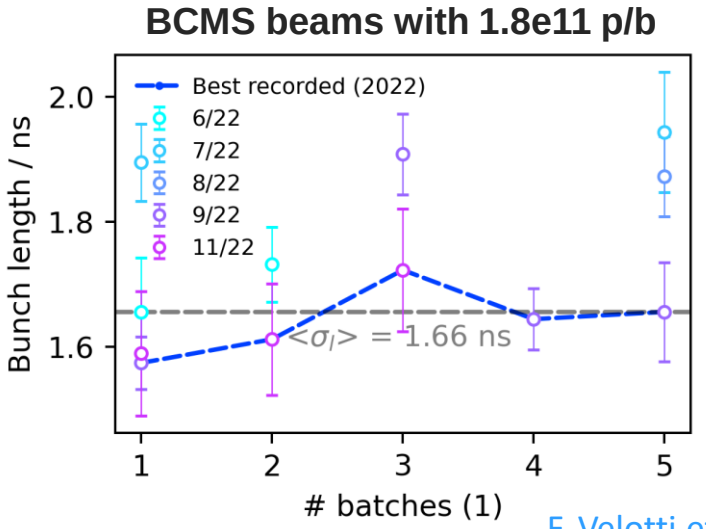
L. Mether et al., SPS MPC #29



C. Zannini et al., JAPW 2022



Pressure spikes at SPS dump kicker MKDH for 25 ns beams



F. Velotti et al., JAPW 2022

- **Pressure spikes limit achievable bunch length at flat top (vacuum interlock)**
  - Strong dependence of pressure spikes on bunch length (short bunches are bad)
  - Best performance for BCMS beam towards the end of the year – **conditioning?**
  - In the last MD of the year **reproduced same vacuum behaviour at ~380 GeV**
  - Need to allocate time after scrubbing to try to condition at lower energy with increased interlock threshold **– extra days in the schedule?**
  - **Increase of interlock thresholds in operation being studied (SY-ABT)**